ANDRILL Targets a Paleogene and Younger Section at Coulman High, Ross Sea, Antarctica to Recover History of the West Antarctic Ice Sheet

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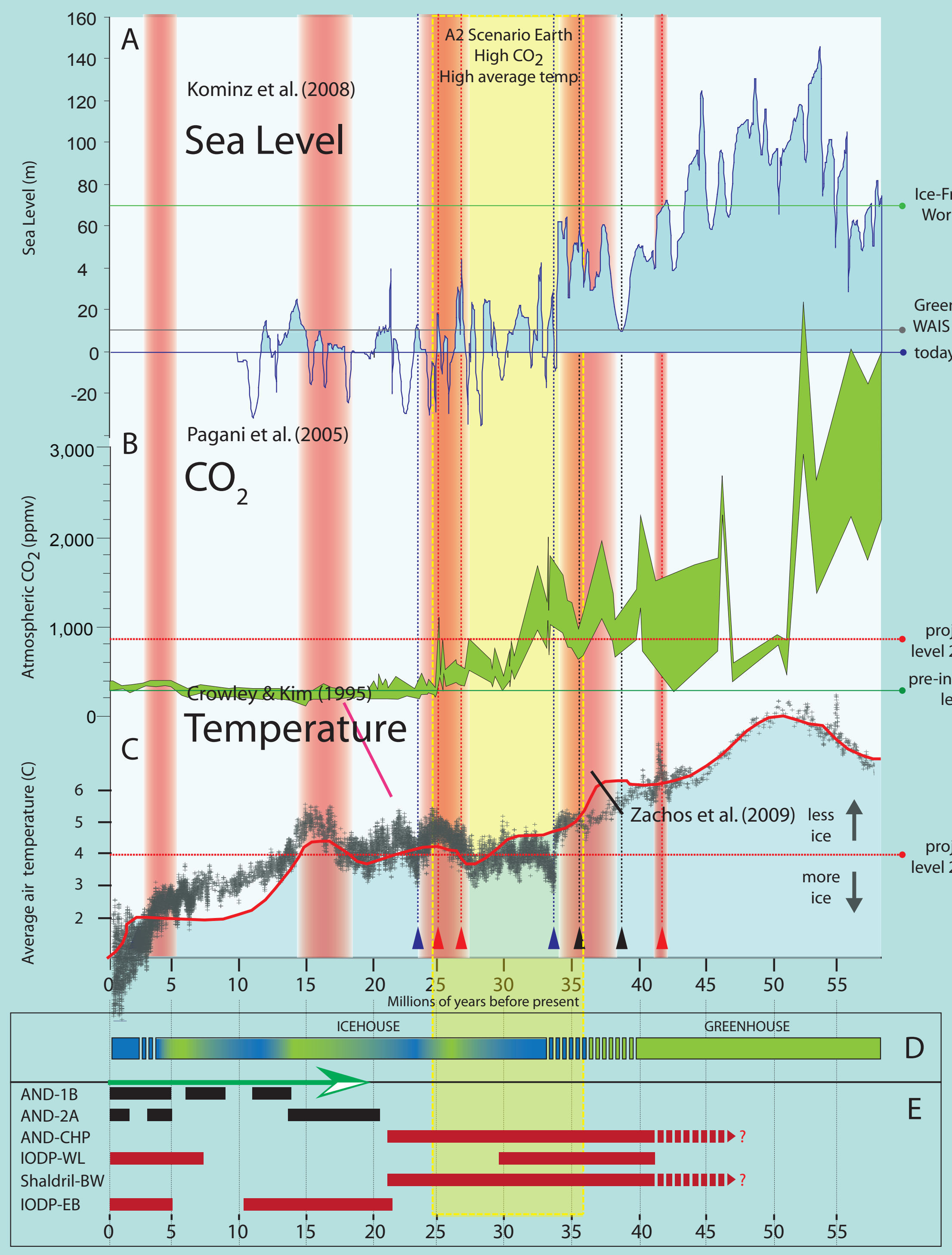
RATIONALE

Drilling at **Coulman High** will investigate: (1) the evolution of the West Antarctic Ice Sheet in a period of high greenhouse gas levels; (2) the Antarctic environment in warm greenhouse periods; (3) controls on Oligocene and Miocene climate and cryosphere; and (4) tectonic processes within the West Antarctic Rift System (Figs. 1, 2).

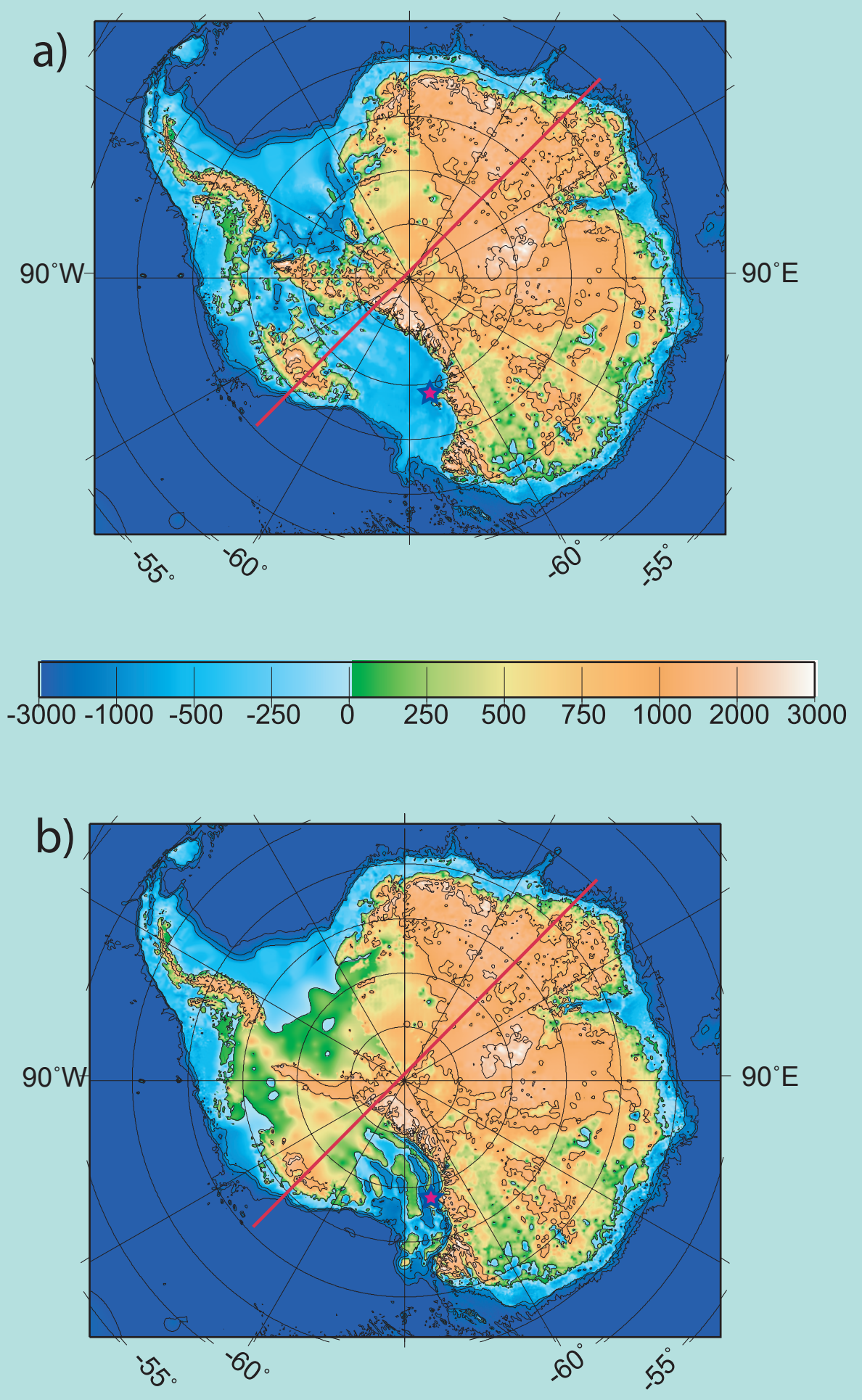
The **ANDRILL Program** completed two 1 km+ holes in McMurdo Sound (MIS, SMS, Figs. 5, 6, 8), and will now move east of Ross Island to the ice shelf over Coulman High. Here it will utilize new drilling capabilities to operate from a fast moving ice shelf platform (~740 m/year northward) and complete two deep holes (**CH-1, CH-2**, Fig. 3). The target for the Coulman High Project is a Cretaceous (?) - Paleogene to lower Miocene section (see correlation to DSDP sites, Fig. 4).

Figure 1 abcde: Proxy data for the past 60 million years :

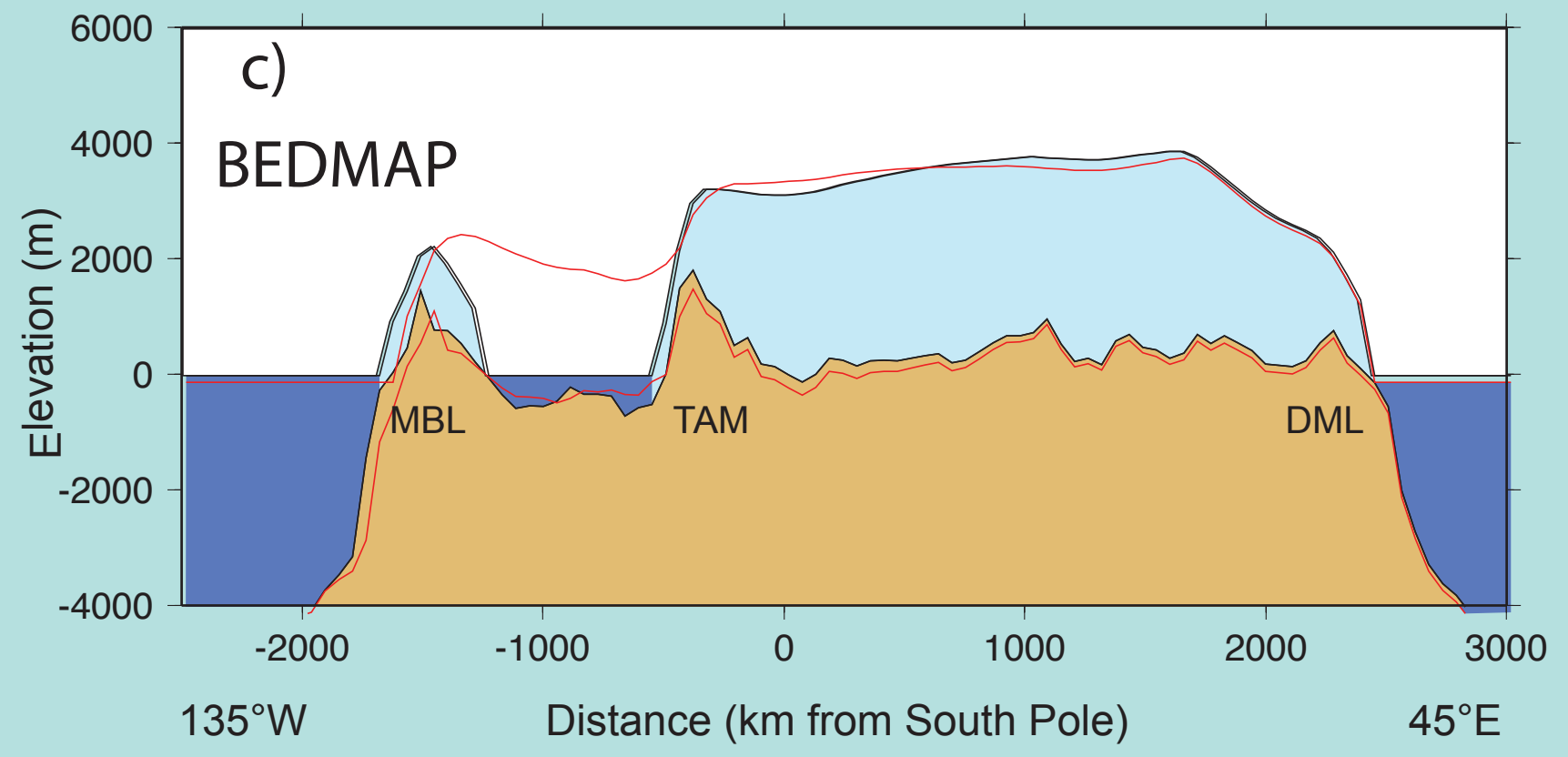


Proxy data for the past 60 million years : A. Eustatic sea level. Horizontal line 1 is the amount of global sea-level rise if both the Greenland Ice Sheet and West Antarctic Ice Sheet were melted and line 2 is amount of global sea-level rise if all present day ice on Earth was melted; B. Atmospheric carbon dioxide levels. The horizontal dashed red line is CO_2 level projected for 2100 AD for the IPCC A2 scenario; C. Global atmospheric temperature curve (bold red) based on deep-sea oxygen isotope records. A compilation of isotope data is in black. Red bands are periods of global warmth. Panel D: Gross scale ice sheet history from deep-sea oxygen isotope records and geologic data from the circum-Antarctic. Panel E: bar chart indicating the geologic time periods previously recovered by ANDRILL (black) and targeted by future drilling projects. The pale yellow box (dashed yellow border) is the period when CO_2 levels and atmospheric temperatures were last at the levels projected for 2100 AD by the IPCC A2 scenario.

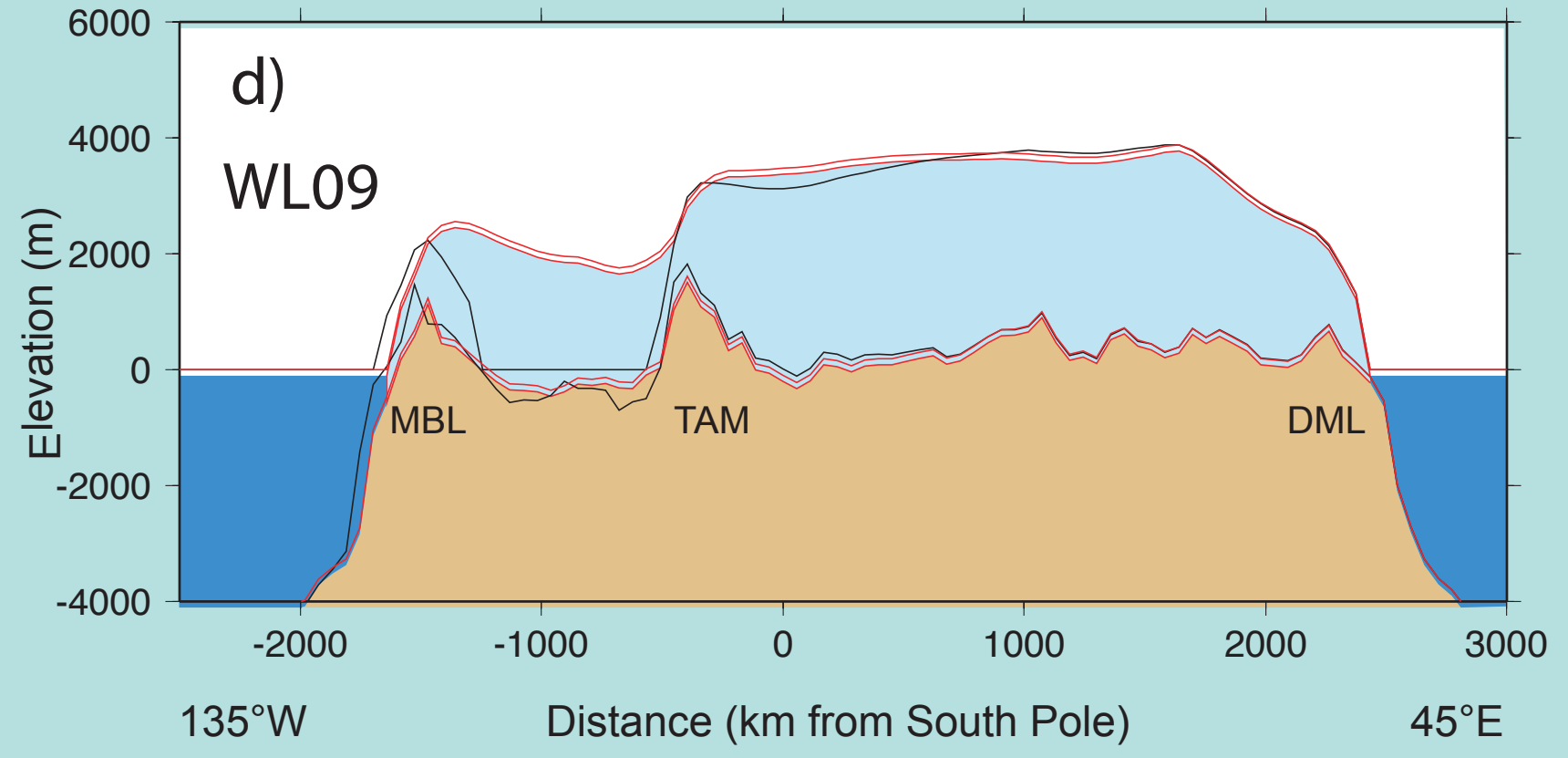
Figure 2: More ice on WANT?


a)
90°W
90°E
-55°
-60°
-60°
-55°
-3000 -1000 -500 -250 0 250 500 750 1000 2000 3000
b)
90°W
90°E
-55°
-60°
-60°
-55°

Ice models by D. Pollard, with E-O climate and isostatic adjustment



Ice models show more ice growth on West and East Antarctica for the WL09 model (d) than for BEDMAP (c).



Maps of Antarctic topography with restorations for removal of the load of modern ice only (a, BEDMAP adj.), and additionally for erosion, sedimentation, thermal contraction, and horizontal plate motion in geologically active regions (b, from *Wilson & Luyendyk (2009)*; WL09). Models correcting only for ice load have been used in all simulations of ice growth (c) to date, but significant changes result from additionally correcting for other geologic processes (d). Star in a and b shows location of CH site.

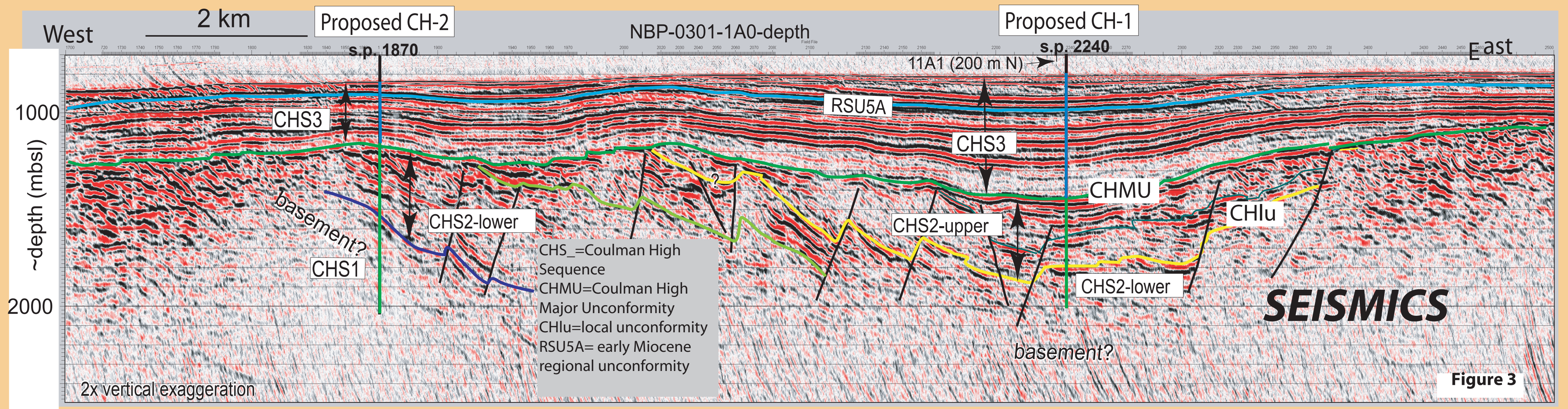

West
2 km
Proposed CH-2
s.p. 1870
NBP-0301-1A0-depth
Proposed CH-1
s.p. 2240
East
11A1 (200 m N)
~depth (mbsl)
1000
2000
CHS3
RSU5A
CHS3
basement?
CHS1
CHS2-lower
CHS2-upper
CHMU
CHlu
CHS2-lower
basement?
CHS_=Coulman High Sequence
CHMU=Coulman High Major Unconformity
CHlu=local unconformity
RSU5A= early Miocene regional unconformity
2x vertical exaggeration
SEISMICS

Figure 3

In 2003 and 2004 a marine multichannel seismic grid was completed as close as 500 m from the front of the Ross Ice Shelf (Fig. 5,6). Since then the ice shelf has migrated north 4 km and now covers some of the survey lines. The plan is to drill through the ice shelf into targets located on those lines. The chosen sites target <600 m of stratified sediments underlain by a major unconformity. The section below the unconformity comprises 350 – 850 m of faulted sediments and basement. Acoustic basement is interpreted to be from 700 to >1500 m below the sea floor.

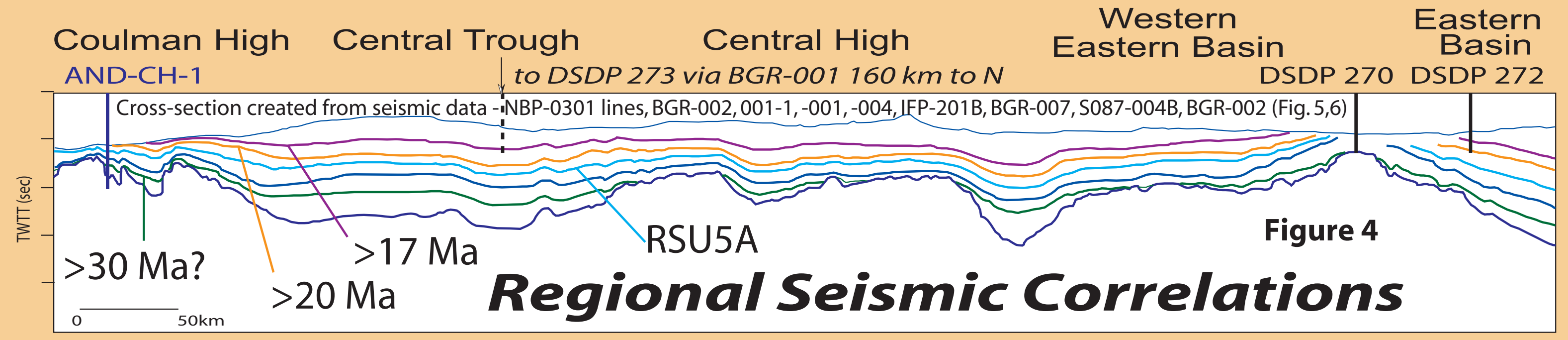

Coulman High
AND-CH-1
Central Trough
Central High
to DSDP 273 via BGR-001 160 km to N
Western Eastern Basin
DSDP 270
Eastern Basin
DSDP 272
Cross-section created from seismic data - NBP-0301 lines, BGR-002, 001-1, -001, -004, IFP-201B, BGR-007, S087-004B, BGR-002 (Fig. 5,6)
TWTT (sec)
>30 Ma?
>20 Ma
>17 Ma
RSU5A
0
50km
Regional Seismic Correlations

Figure 4

Seismic correlation from DSDP Site 273 within Central Trough and Site 272 in the Eastern Basin to the Coulman High sites implies that the section proposed to be drilled predates 19 Ma. These correlations imply that the section at Coulman High would be older than the early Miocene and younger climate record from ANDRILL sites in McMurdo Sound (Fig. 1 Panel E).

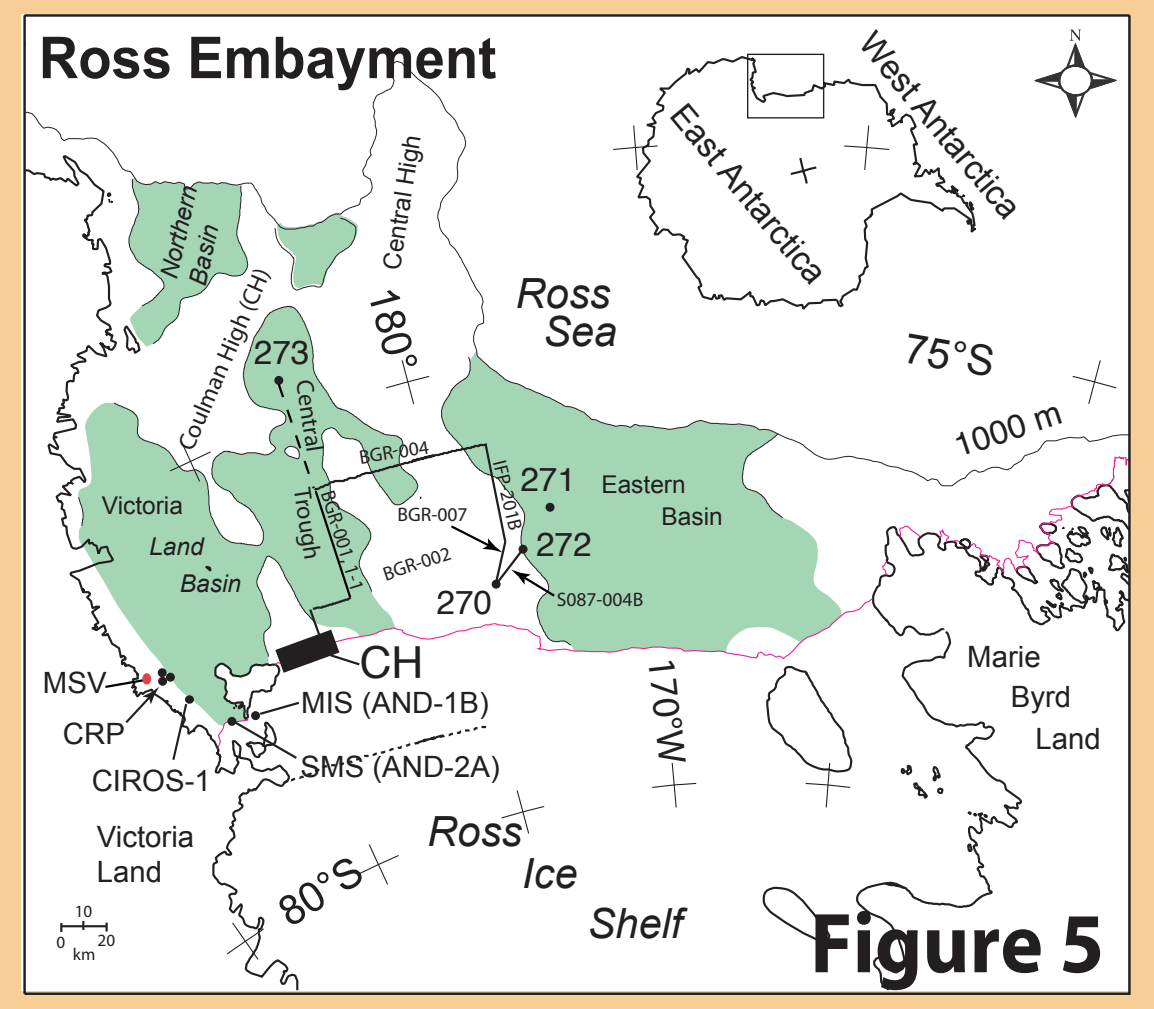

Ross Embayment
West Antarctica
East Antarctica
Northern Basin
Central High
Coulman High (CH)
273
Central Trough
180°
Ross Sea
75°S
1000 m
BGR-004
BGR-007
BGR-002
BGR-001-1
IFP-201B
271
Eastern Basin
272
270
S087-004B
Victoria Land Basin
CH
MSV
CRP
CIROS-1
MIS (AND-1B)
SMS (AND-2A)
170°W
Marie Byrd Land
Victoria Land
80°S
Ross Ice Shelf
10
0 km 20

Figure 5

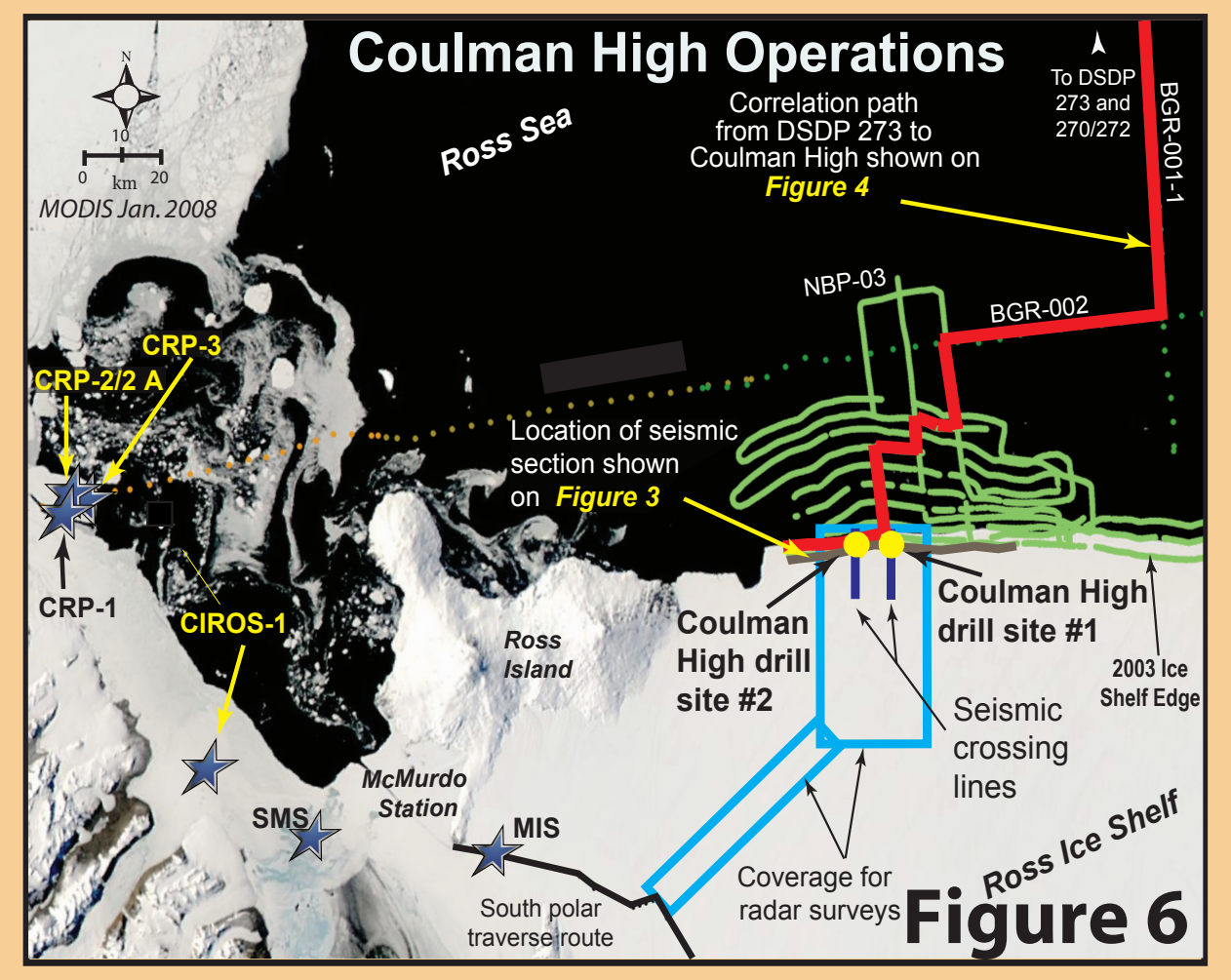
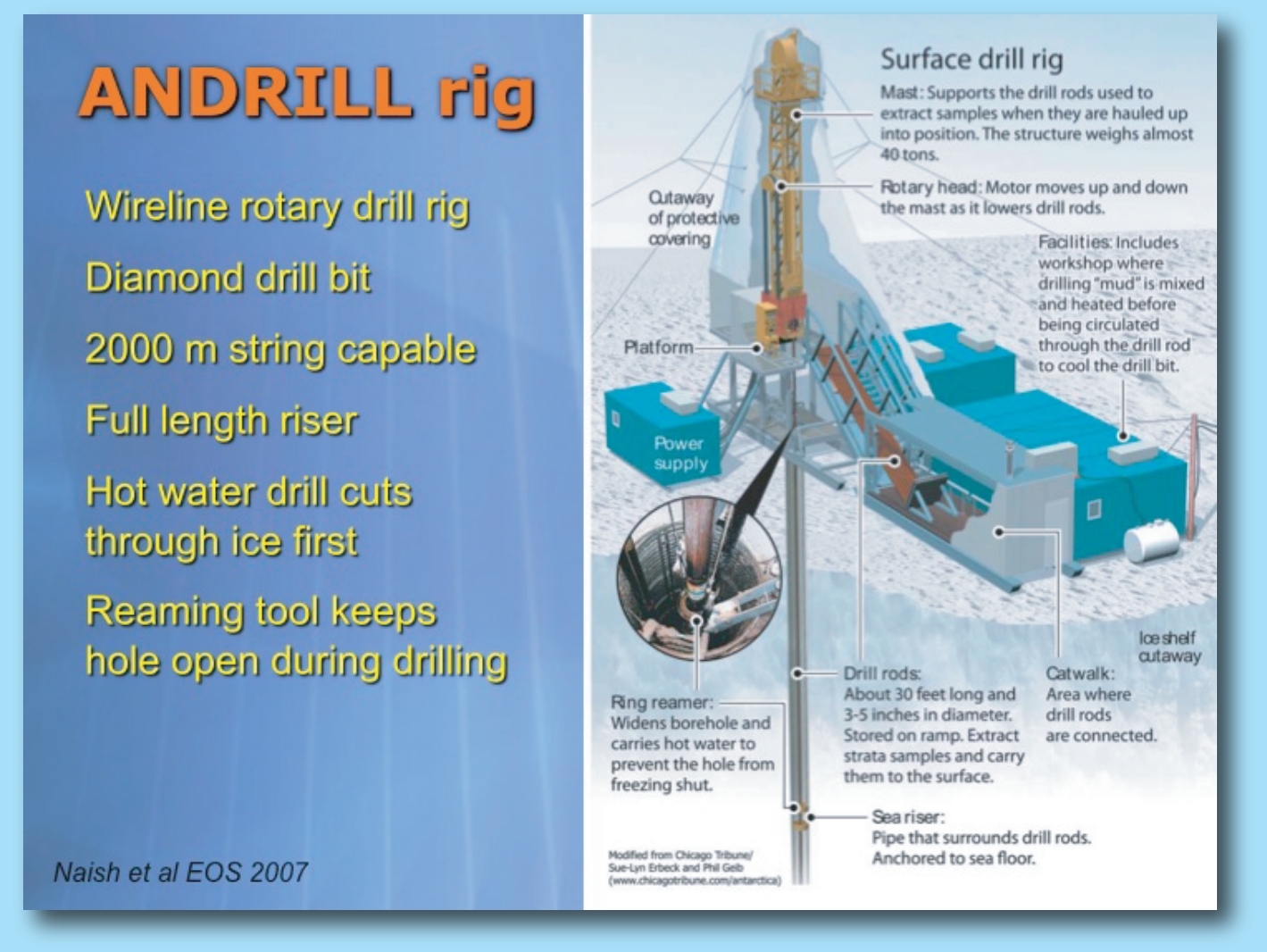

Coulman High Operations
Ross Sea
MODIS Jan. 2008
Correlation path from DSDP 273 to Coulman High shown on Figure 4
To DSDP 273 and 270/272
BGR-001-1
NBP-03
BGR-002
CRP-3
CRP-2/2 A
CRP-1
CIROS-1
Location of seismic section shown on Figure 3
Coulman High drill site #1
Coulman High drill site #2
2003 Ice Shelf Edge
Seismic crossing lines
Ross Island
McMurdo Station
SMS
MIS
South polar traverse route
Coverage for radar surveys
Ross Ice Shelf

Figure 6



ANDRILL rig

- Wireline rotary drill rig
- Diamond drill bit
- 2000 m string capable
- Full length riser
- Hot water drill cuts through ice first
- Reaming tool keeps hole open during drilling

Naish et al EOS 2007

Surface drill rig

Mast: Supports the drill rods used to extract samples when they are hauled up into position. The structure weighs almost 40 tons.

Rotary head: Motor moves up and down the mast as it lowers drill rods.

Facilities: Includes workshop where drilling "mud" is mixed and heated before being circulated through the drill rod to cool the drill bit.

Cutaway of protective covering

Platform

Power supply

Ice shelf cutaway

Ring reamer: Widens borehole and carries hot water to prevent the hole from freezing shut.

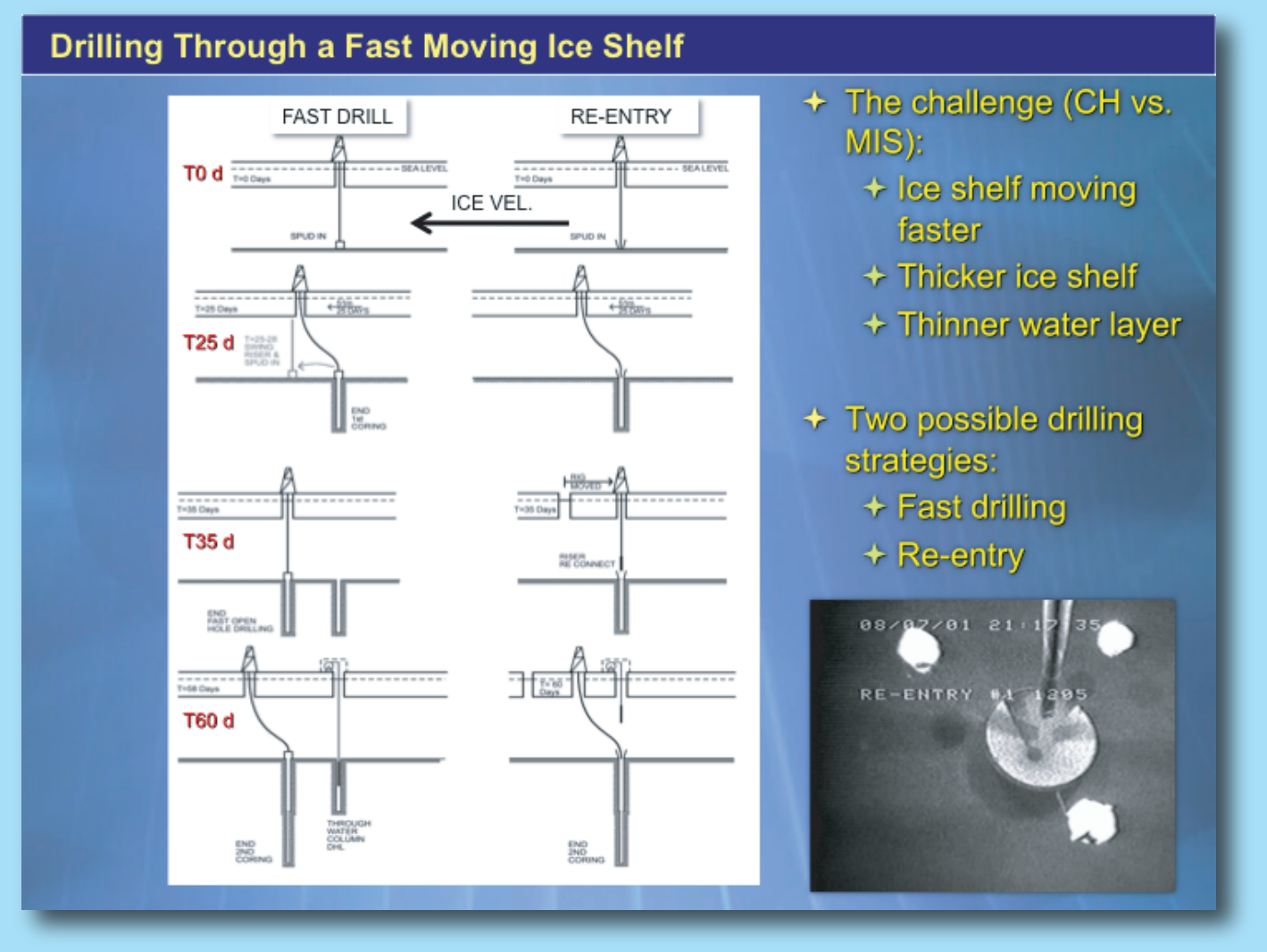
Drill rods: About 30 feet long and 3-5 inches in diameter. Stored on ramp. Extract strata samples and carry them to the surface.

Catwalk: Area where drill rods are connected.

Sea riser: Pipe that surrounds drill rods. Anchored to sea floor.

Modified from Chicago Tribune/ Sue-Lyn Erbeck and Phil Geib (www.chicagotribune.com/antarctica)

Figure 7a



Drilling Through a Fast Moving Ice Shelf

- The challenge (CH vs. MIS):
  - Ice shelf moving faster
  - Thicker ice shelf
  - Thinner water layer
- Two possible drilling strategies:
  - Fast drilling
  - Re-entry

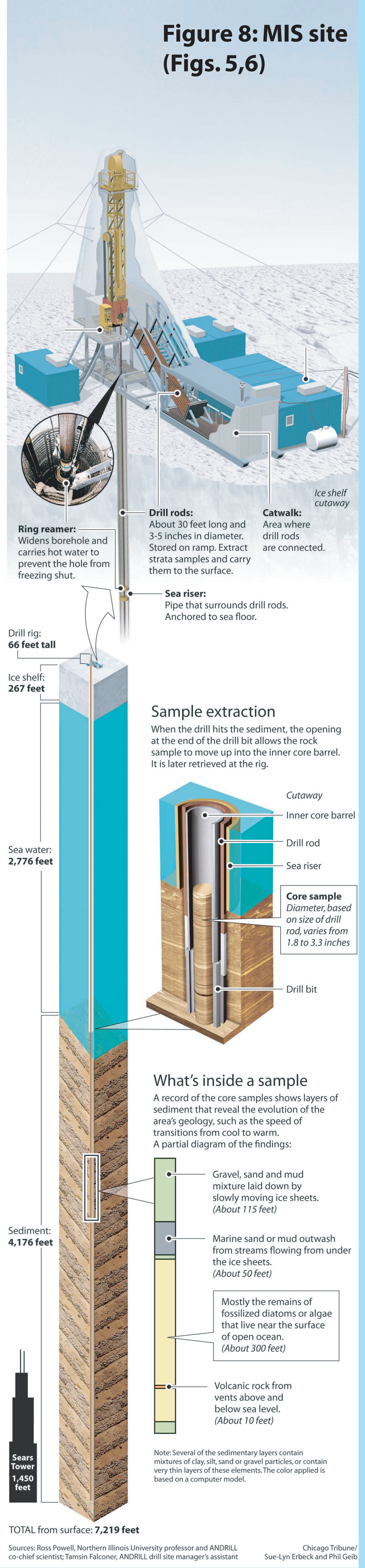
FAST DRILL
RE-ENTRY
T0 d
T25 d
T35 d
T60 d
ICE VEL.
SEA LEVEL
SPUD IN
END 1st CORING
END FAST OPEN HOLE DRILLING
RISER RE CONNECT
THROUGH WATER COLUMN DHL
END 2ND CORING
08/07/01 21:17:35
RE-ENTRY #1 1295

Figure 7b

Drilling will require melting through the ice shelf with a hot water drill. Operational challenges will result from the movement of the ice shelf northward over the sea floor at ~2 m/day. Deflection of the riser cannot be more than 8% of the water layer thickness of 630 m (below ice base) and constrains drilling depth to a maximum of ~500 m. To reach targets at > 1000 m below sea floor, two options are being considered; to pull out and move the rig back over the site and reenter the hole, or to pull the string at the end of the drilling and wash down to the prior depth at a new offset site and drill and core below that depth (Fig. 7b; d = days).

DRILLING

Figure 8: MIS site (Figs. 5,6)


Ring reamer:
Drill rods:
Catwalk:
Ice shelf cutaway
Sea riser:
Drill rig: 66 feet tall
Ice shelf: 267 feet
Sea water: 2,776 feet
Sediment: 4,176 feet
Cutaway
Inner core barrel
Drill rod
Sea riser
Drill bit
Sears Tower 1,450 feet

Ring reamer: Widens borehole and carries hot water to prevent the hole from freezing shut.

Drill rods: About 30 feet long and 3-5 inches in diameter. Stored on ramp. Extract strata samples and carry them to the surface.

Catwalk: Area where drill rods are connected.

Sea riser: Pipe that surrounds drill rods. Anchored to sea floor.

Sample extraction

When the drill hits the sediment, the opening at the end of the drill bit allows the rock sample to move up into the inner core barrel. It is later retrieved at the rig.

Core sample *Diameter, based on size of drill rod, varies from 1.8 to 3.3 inches*

What's inside a sample

A record of the core samples shows layers of sediment that reveal the evolution of the area's geology, such as the speed of transitions from cool to warm.
A partial diagram of the findings:

- Gravel, sand and mud mixture laid down by slowly moving ice sheets. *(About 115 feet)*
- Marine sand or mud outwash from streams flowing from under the ice sheets. *(About 50 feet)*
- Mostly the remains of fossilized diatoms or algae that live near the surface of open ocean. *(About 300 feet)*
- Volcanic rock from vents above and below sea level. *(About 10 feet)*

Note: Several of the sedimentary layers contain mixtures of clay, silt, sand or gravel particles, or contain very thin layers of these elements. The color applied is based on a computer model.

TOTAL from surface: **7,219 feet**

Sources: Ross Powell, Northern Illinois University professor and ANDRILL co-chief scientist; Tamsin Falconer, ANDRILL drill site manager's assistant

Chicago Tribune/ Sue-Lyn Erbeck and Phil Geib